

Technologies for Networked Enabled Operations

B. Glass
And
J. Levine

NASA Ames Research Center
Moffett Field, CA 94035
Brian.Glass@nasa.gov

Abstract

Current point-to-point data links will not scale to support future integration of surveillance, security, and globally-distributed air traffic data, and already hinders efficiency and capacity. While the FAA and industry focus on a transition to initial system-wide information management (SWIM) capabilities, this paper describes a set of initial studies of NAS network-enabled operations technology gaps targeted for maturity in later SWIM spirals (2015-2020 timeframe).

Introduction

To make revolutionary transformational improvements in airspace operations future National Airspace Systems (NAS) components and subsystems will need to be flexible, real-time re-configurable, and able to trade data, transparently, amongst themselves. On-board aircraft systems, air traffic capacity improvements, air space security and coordination with airline commercial operations and general aviation users all required real-time modular reconfigurability and data sharing, but the NAS current information systems are, largely, legacies from quickly developed, obsolescent, 1970's

stand alone systems. Today's aircraft, ground support equipment, air space surveillance, air traffic management applications, and data links are not able to "plug and play", Lego-like into different combinations. Point to point dominates – individual radar to individual TRACON, individual aircraft to controller are all locally optimized, all are unique. Each of the data interfaces has been coded for each possible one-to-one combination. This operations and maintenance nightmare adversely impacts both NAS security and capacity. This legacy approach is not scaled to the tens of thousands of components that will be networked together in the future. [Refs 1-4] By comparison, battlefield information management systems, which are considered critical to military force projections, have long since abandoned this point-to-point approach.

A "clean-sheet" redesign of the data management of all NAS systems is a necessary prerequisite for the transformation of the NAS. The existing commercial communications and the DoD's Global Information Grid and middleware technologies are probably sufficient for command, control and information interfaces with some hardware and real-time modifications for air traffic management environments. Future NAS air traffic operations must also be information – data- compatible with airspace operations and surveillance systems now being developed by the Department of Homeland Security as well as the Department of Defense.

The benefits of widespread information sharing among many airspace information users has been apparent for over a decade. Beginning in the early to mid 1990s, the Surface Movement Advisor (SMA) was developed and deployed as a prototype at Atlanta's Hartsfield Airport [Ref 5]. SMA allowed airport users from the FAA and airline management to share data in real time between each other, improving situational

awareness of all parties. The success of SMA in Atlanta led to a national utilization subsequently. In the late 1990s, Eurocontrol formulated its System Wide Information Management (SWIM) concept for system-wide information sharing analogous to that which had been done previously with SMA in Atlanta. The SWIM concept as well as NAS-wide information sharing formulated by the FAA in the past 5 years has combined to lead to prototype SWIM implementation by the FAA and its contractors over the next several years [Refs 6,7].

Technologies for Network Enabled Operations (TNEO) expands on the scope of the prototype SWIM proposed for the NAS and being implemented by the FAA by looking at aviation security, safety, and global information grid compatibility as well as NAS communications integration issues. A fully functional SWIM is not possible with today's COTS middleware, given the number and movement of aircraft and other vehicles active in the NAS at any given time. While FAA and NAS plan to implement parts of SWIM in the next 3 years for the sake of sharing surveillance data, the addition of NAS wide coverage, and sufficient robustness and certifiability for managing traffic, will be a decade or more off [Ref 8]. This paper will examine the applicability of TNEO to the longer-term technology gaps needed to create nationwide real time data sharing and routing in the 2015 – 2020 time frame.

In some sense, Network Enabled Operations (NEO) in the NAS domain can be thought of as analogous to a package courier service – it doesn't build or operate the runways or roads (analogous to communications or network hardware) but it tags and conveys data from its origin to its addressed destinations providing security and tracking while in route. Research into TNEO by NASA can be then thought of as analogous to

designing a package routing system with sorting facilities and localized trunk distribution, sufficient for future 10 year distant workloads -- as well as the specific automated databases of middleware (analogous to developing bar code scanners and specialized cargo handling equipment).

This paper will look at the need for widespread improved situational awareness and data sharing as it effects both TNEO and the near term SWIM implementations. It will then discuss how data sharing amongst various NAS user classes can improve situational awareness for each class, and finally will outline a NASA research program that will address the technology gaps currently in place.

Problems and Challenges

There are several NAS problems addressed by both SWIM and TNEO. Among them are poor information sharing leading to efficiency losses, Another problem is the lack of common situational awareness or flight and weather status making it difficult to implement collaborative, tactical, strategic decision-making. Any collaboration between centers in the air traffic system, to combine sectors dynamically is not possible without real-time data sharing capabilities and accessible surveillance from other data sources. We look to enable the development of information sharing and data acquisition in a framework that we can share with all affected communities, including both air traffic management and aviation safety and national security that will enhance the situational awareness tactically and strategically of all those communities. Informed decision making in a dynamic National Airspace System environment will require real-time information distribution whether during routine, planned, or crisis events.

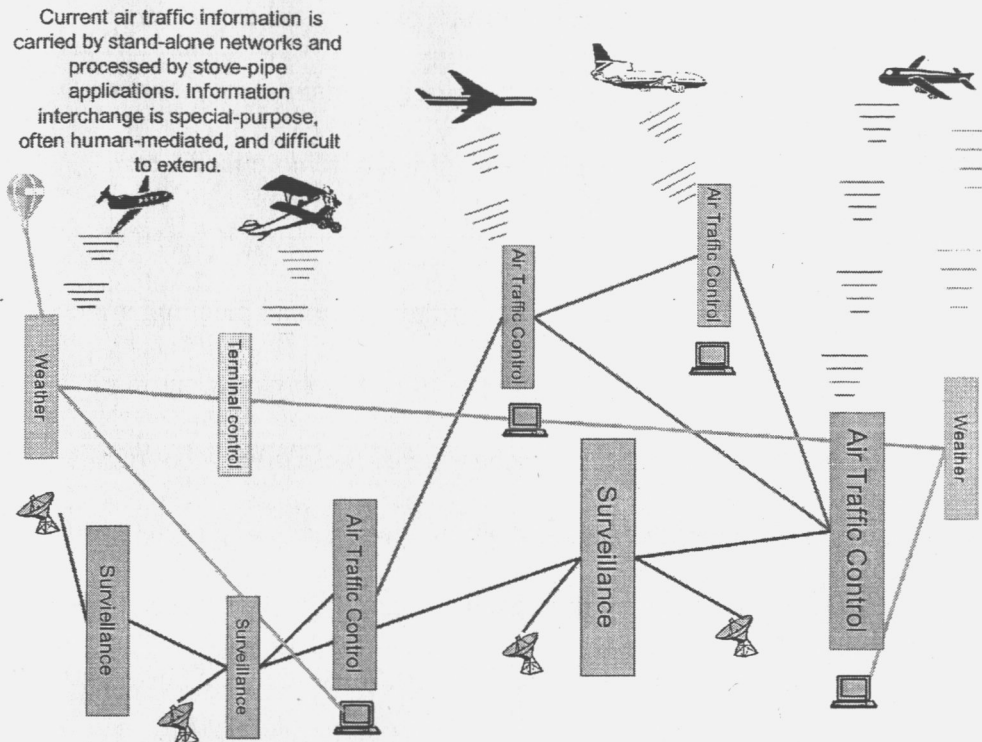


Figure. 1. Standalone dedicated interfaces in the current airspace system

increase maintenance costs and operational complexity. (Fig: R. Filman)

Planned SWIM implementation will shift the NAS architecture, initially, from point to point distribution. Oceanic, terminal, surface, airline and en-route databases, each of which, currently communicate point to point or have custom one-off database interfaces, will change in SWIM to common information sharing through middleware layers, through common standards and published and subscribed architectures. This will enabling NAS users, developers and maintainers to define interfaces once, rather than many times for many different interfaces between systems (Fig. 1). Otherwise the proliferation of interfaces becomes a maintenance nightmare and demands an information-centered approach to revise them.

The current NAS has many nonintegrated pieces. Independently performing computers support each air traffic domain, each with its own limited computing capability and no means of sharing resources. It is, largely, a mainframe computer architecture that performs its functions from multiple globally remote facilities. Individually these facilities are functionally robust and there is a set of distributed communications, command and control, navigation, surveillance and planning systems that each function well independently, but they are not linked to any crosscutting architecture. Automation of the data flow and processing of these diverse sources is desirable in networked decision support tools and applications that can present a more graspable and real-time event awareness and understanding of operational situations. To access this real-time data from multiple air traffic domains, there will be a need to design and implement an integrated systems architecture that is scaleable, system-wide in scope and with low latencies to enable real-time decision-making. The architecture must also be extendable to accommodate future increases in demand for air traffic and other transportation data. A significant challenge will be to provide an integrated, graspable, system-level picture of the past, present and planned state of the air transportation system to serve as a common basis for decision-making.

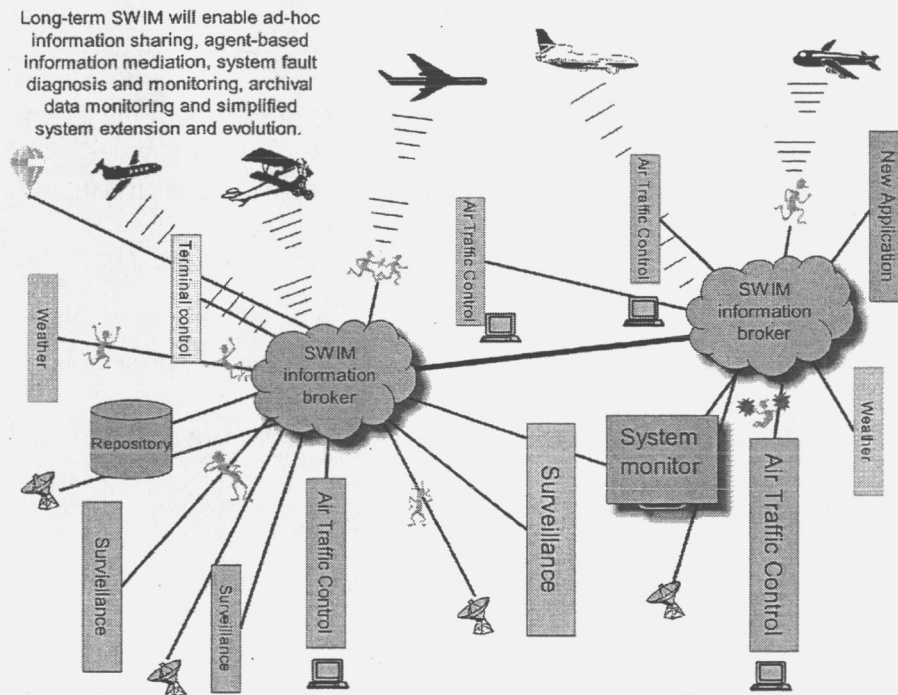


Figure 2. SWIM information-brokering architecture will require some NEO technologies. (Fig: R. Filman)

In addition to the data distribution and the improved situation awareness and safety needs that will be reflected in initial SWIM implementations, there will be additional requirements that will be drawn from the current Joint Planning and Development Office (JPDO) integrated product teams [Ref 9] who are looking at shared situational awareness as well as air traffic implementations in the Next-Generation Air Transportation System (NGATS). Specific to air traffic, however, preliminary results from the shared situational awareness IPT specified several NGATS desired outcomes that would be applicable to future NEO technologies. Several directions are specified from the early JPDO results: Action Plan 1 will enable services that are tailored to travel or shipper needs. Action Plan 2 seeks to increase predictability and minimize the impact

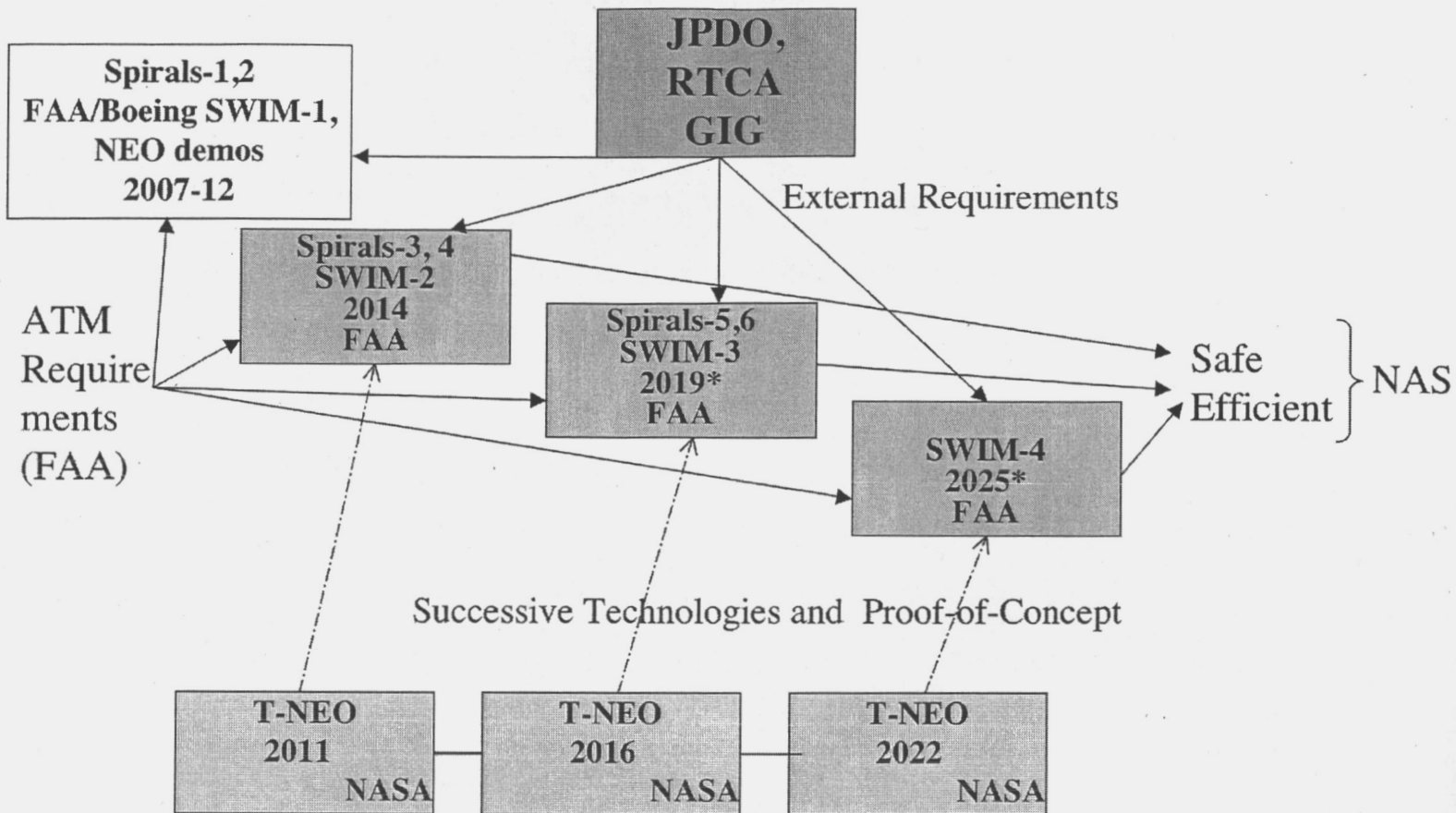
of weather and other disruptions, Action Plan 3 enables the coordination of a national response to threats as well as to ensure that security measures still enable the efficient service to demands, and Action Plan 4 allows for the provision of the common defense while minimizing the constraints on the civilian air traffic and air travel.

Approach

When considering what technologies and technology gaps need bridging for NEO, or for a SWIM architecture (Fig. 2), our objectives were to find out what technology was needed specifically for future NAS-wide information management. We looked to develop a strawman information management architecture for the NAS, with inputs from FAA and NAS users, that will build from the current NAS and from the FAA's initial prototype SWIM (Spirals 1 and 2) to meet future NAS requirements while integrating with the Global Information Grid being developed by other government organizations [Ref 10]. Another objective was to identify which relevant technologies could be fostered using a combination of commercial or other government or new NASA research.

However, network-enabled operations technologies have a broader scope than just air traffic management. Other government agencies are concerned with military applications and managing the Global Information Grid, or with the security implications of the use of surveillance and other data that might derive from the air traffic system. Even in the NAS, there are many views of what is transpiring at any given moment. The vehicle operator or airline view will be different from the airport business operator's view, which will be different than the air traffic TRACON view, which will be different than the individual pilot's view, or airline operations view. Air traffic management will

be concerned with decision management, group management, arrivals, departures, surface traffic flow, flight planning -- but other operators and other participants in the NAS will be interested in different real-time data, such as vehicle status, payload, navigation information, specific airport information, weather and environmental information -- even the location of airport food trucks. These have implications for NAS efficiency, and security/safety considerations, as well as air traffic considerations. We expect these considerations to be reflected in several different layers and subsets of data flow and data exchange with access to given data and data pools limited to those who have a need to know for operational reasons.



* Notional Future NAS Updates

Figure 3. NEO technology cycles assumed in gap assessments.

To do an initial assessment of what gaps existed that would be appropriate for a NASA research program over the past two years, the authors and others within NASA have conducted a series of studies and workshops aimed at identifying gaps in technologies for network enabled operations as well as individual SWIM implementations. We considered both published sources such as FAA reference documents and the RTCA NAS concept of operations, as well as early feedback from the JPDO working groups. The process is shown in Figure 3. In assessing what technology

gaps exist in the NAS for information sharing, we considered all technology needs beyond the state of the practice (the NAS), including areas that are best served, currently, by forecast commercial or industry capabilities as well as any government R&D. In our analysis we identified 5 separate areas of NEO technology gaps in the NAS that pertained to information sharing and network enabled operations.

Communications is critical, although much of that area will be covered with DoD or Global Information Grid sponsored research, being done elsewhere. There are some specific air-to-ground communication gaps and needs that will still remain to be addressed within the NAS, apart from those GIG-provided. Other areas of technology gaps identified were integration of subsystems in NAS components; development of replacement server and networking communication hardware replacing current FAA systems; software technologies, including automated agents, to avoid having excessive human or operator inputs for regulating data transfer, handling, and transmission. And testing and flight rating of data transfer protocols and displays. Figure 4 shows one such set of gaps that were done for software gap analysis looking at both identified gaps, a likely approach and what relevant project expectations were found within NASA. This includes areas such as system health management, the use of intelligent agents for managing SWIM, data mining, data base validation, or anomalous data identification. One new area that was found was the need for some form of data cleansing because information shared amongst many databases continually on a 24/7 basis will not be easily fixed or expurgated if the database is corrupted. Some methods will be needed to cleanse or purge a running real-time database that has acquired corrupt data -- whether due to hostile action or to simple sensor failure. Figure 3 shows several spirals of prototyping

Gap	Likely Approach	Relevant Project Experience
SWIM system self-monitoring	Autonomic hardware computing technologies from industry, Network Mgt	Not addressed yet Network Enabled Operations 12
SWIM system health management and automatic recovery	Combination of Govt and COTS; further R&D (no one is addressing as yet)	IVHM support has dwindled in vehicle systems, shifted to space science
Intelligent Agents	NASA or DoD-sponsored technologies, universities	ARC - ARA and CAS groups and surface ATC; JPL automation group
Data mining	Combination of Govt and COTS	CSFC, earth sciences ARC - statistical methods
Projection, trending, prognostics	Domain-specific, FAA and contractors	Active Objects - COTS
Database Validation	Combine COTS tools with Govt. domain knowledge	ARC - ARA group, JPL, Av. Safety I, 2 Probably outsourced
Data Cleansing	New R&D	Still a research topic
Heterogeneous software environments	Grids	ARC, GRC, Harris
Anomalous data ID and compensation	Meta-data generation from large databases	Boeing, ARC, CSC

and capability, beginning with the current SWIM being developed by the FAA and its contractors in the near-term leading to network enabled operations in integration with the global information grid air traffic management over the next 10-15 years in iterative releases and spirals. The NASA TNEO program proposed would develop long-lead term items that address the technology gaps not otherwise addressed by other government agencies or industry development in these time periods.

Figure 4. Sample from NEO technology gaps analysis, for software.

From NASA internal R&D activities in air space systems there are also several air traffic management needs that would be addressed by TNEO -- among them are several constraints:

- Timeliness of information should not be a constraint for transferring information.

- Going from 15 to 50 aircraft per controller will require automatic data handling, data tagging, routing, archiving of messages.
- The NAS must have accuracy in availability of data that must be sufficient to achieve capacity and efficiency requirements – existing time lags must not worsen and new capabilities of software must not route directly to wrong places.
- TNEO must reduce time and cost to develop and certify new NAS software by providing common data formats, common CNS utilities, and common development and integration process.

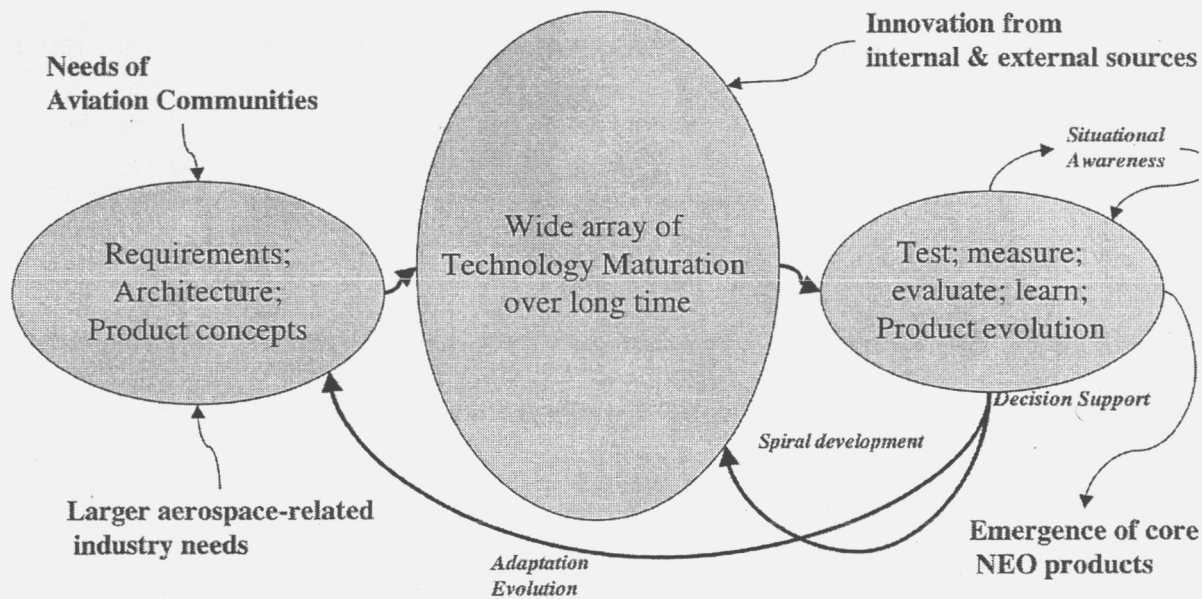


Figure 5. Goal seeking spiral development flow, used to organize and address

NEO and SWIM technology gaps.

Rather than organize TNEO along disciplinary lines it was felt that to most closely track development spirals in other governmental agencies, in the FAA, and in the

JPDO process, we would follow a spiral development plan (Figure 5) in our organization of the technology gaps into a coherent whole. Considering the needs of aviation communities, innovation of external and internal sources, the needs of larger airspace related industries, airlines, and finally, leading to the emergence of core NEO products for implementation in the NAS, and integration in the overall global information grid.

Figure 5 shows a goal seeking, systems engineering spiral development flow, used to organize these gaps into an array of technology maturation areas leading to tests and cycling back into technology development again. These areas cover the identified gaps that commercial or other government agencies are not expected to address. They include NAS specific aspects of security and integrity assurance, modeling of specific distributed information of air traffic management, data definition and processing using autonomous or intelligent agents in real time, as well as support for TNEO as well as early SWIM architecture development and definition, and technology road mapping.

Proof of concept testing and demonstration and evaluation will then place these technologies into a realistic networked operations prototype environment to refine and increase the maturity of these technologies, partnered with industry and the FAA for use in future SWIM and NEO products.

Expected Results

We expect to formulate a set of technology maturation tasks that will deliver new capabilities and mature technologies for implementing network-enabled operations in the national air space system. These tasks will provide deliverables:

- Bridging legacy systems to improvements
- Candidate evolvable and extendable architectures
- Proof of concept information tools
 - Data fusion and mining
 - Intelligent management of security and integrity of system-wide information
 - Data to support transformational operations
- Proof of concept system simulation with system-wide tools and components included.

While the initial system wide information management capability currently being developed will be focused on serving transitional FAA requirements, we must also look beyond that to the on-going national transformation and information sharing which is net-centric, looks to space, considers security and is integrated with an overall global information grid. We expect that NEO technologies will improve the safety, flexibility, efficiency, and capacity of the future NAS while reducing the cognitive load on all types of users (e.g. pilots, controllers, airline operators, etc.) through improved situational awareness built on seamless information sharing, globally. Future technologies for NEO will also include the automation of the management of these networks by the use of software agents – intelligent information systems that can adapt to use real time and historical knowledge of patterns of aircraft, airspace, and airport performance to increase the overall safety, security and efficiency of the movement of air traffic throughout the system.

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Technologies for Network-Enabled Operations (TNEO)

B.J. Glass and J. Levine

NASA-Ames Research Center, Moffett Field, CA

To make revolutionary, transformational improvements in airspace operations, future National Airspace System (NAS) components and subsystems will need to be flexible, real-time reconfigurable, and able to trade data transparently among themselves. Onboard aircraft systems, air traffic capacity improvements, airspace security and coordination with airline commercial operations and general aviation users all require real-time modular reconfigurability and data sharing. But the NAS's current information systems are still largely legacies from hastily-developed, one-off 1970s standalone systems. Today's aircraft, ground support equipment, airspace surveillance, air traffic management applications, and datalinks are not able to plug-and-play, Lego-like, into different combinations. Point-to-point dominates – individual radar to individual TRACON, individual aircraft to controller. All are locally optimized, all unique, each of the data interfaces has been coded for each possible one-to-one combination. This operations and maintenance nightmare adversely impacts both NAS security and capacity. This legacy approach does not scale to the tens of thousands of NAS components that will be networked in the future. By comparison, battlefield information management systems, which are considered critical to military force projection, have long since abandoned the NAS's current point-to-point approach.

From a system-of-systems viewpoint, a revolutionary, clean-sheet redesign of the data management of all NAS systems is a necessary prerequisite to the transformation of the NAS. Existing commercial communications and the DoD's Global Information Grid and middleware technologies are probably sufficient for command and control and information interfaces, with some hardware and real-time modifications for air traffic management environments. Future NAS air traffic operations must also be information- and data-compatible with aerospace operations and surveillance systems being developed by the Department of Homeland Security and Department of Defense.

In some sense, Network-Enabled Operations (NEO) in the NAS domain can be thought of as analogous to a package courier service – it doesn't build or operate the runways or roads (analogous to communications and network hardware) but it tags and conveys data from its origin to its addressed destination(s), providing security and tracking while en route. Research into technologies for NEO (TNEO) by NASA can then be thought of as analogous to designing a package routing system, with sorting facilities and localized and trunk distribution, as well as the specifics of automated databases and middleware (analogous to developing barcode scanners and specialized cargo handling equipment).

TNEO expands on the scope of the system-wide information management (SWIM) proposed for the NAS by looking at aviation security, safety, and GIG-compatibility as well as NAS communications integration issues. A functional SWIM is not possible with today's COTS middleware (stretching the analogy to supermarket scanners) given the number and movement of aircraft and other vehicles active in the NAS at any given time.

FAA and DHS plan to implement parts of SWIM in the next three years for the sake of sharing surveillance data, but NAS-wide coverage sufficient for managing traffic will be a decade or more off. This paper will examine the applicability of TNEO to the longer-term technology gaps needed to create nation-wide realtime aviation data sharing and routing in the 2015-2020 timeframe.

TNEO will improve the safety, flexibility, efficiency, and capacity of future NAS, while reducing the cognitive load on all types of users (e.g. pilots, controllers, airline operators) through improved situational awareness built on seamless information sharing. Currently information is required from numerous disparate sources, but with GIG and SWIM technologies the users will be able to access all the information available on the NAS, anytime, anywhere to the extent authorized. Future TNEO will also include networks of software agents -- intelligent information systems that can adaptively use real-time and historical knowledge of aircraft, airspace, and airports, to increase the safety, efficiency and flexibility of movement of air traffic through the system.